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Energy Conservation in Present and Future Ships

Summary Report

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- SUMMARY REPORT -

ENERGY CONSERVATION IN PRESENT AND FUTURE SHIPS

TP6985E

For

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17. Abstract

This reference document provides a summarized compendium of information on current practice and potential future developments in the area of energy conservation on ships. It presents information on fuel quality and equipment, propulsion power systems, thrust system, auxiliary systems, ship resistance, ship operation, the application of fuel efficiency measures to various Canadian ships, future fuels and power sources, and future propulsion systems and equipment. It discusses existing technology and future developments with special reference to the application of this technology to Canadian vessels.

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17. Résumé

Ouvrage de référence constituant un compendium sur les techniques présentes et futures en matière d'économie d'énergie à bord des navires. L'information fournie concerne: les combustibles (qualités et équipements), les installations motrices, le système propulsif, les systèmes auxiliaires, la résistance à l'avancement du navire, l'exploitation du navire, les mesures d'économie d'énergie appliquées à bord de divers navires canadiens, les combustibles et les installations motrices de l'avenir ainsi que l'évolution future des systèmes et des équipements de propulsion. De plus, il traite des technologies actuelles et futures, en général, et de leurs utilisations sur les navires canadiens, en particulier.

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1.0 INTRODUCTION

In the years prior to 1973, the cost of fuel amounted to less than 8% of a ship's operating costs. Since that time the price of fuel oil has progressively risen to 7 times the pre-1973 figure and fuel costs now amount to more than 30% of the ship's operating costs. In addition, many analysts have predicted that natural oil will start to be depleted by the year 2000. This combination of circumstances has encouraged the worldwide trend towards improving the existing efficiency of ships.

This report documents a study carried out by Melville Shipping Ltd. (Melville) as a cost shared project with the Transportation Development Centre (TDC). The study's principal objectives were to review the development of marine technology for the future energy-efficient ship and to forecast the most probable future developments. The study is intended to be of particular interest to shipowners and shipbuilders by providing a guide to the choice of marine power plant, and to those in Government responsible for stimulating marine research and development.

The report has been organized in a logical sequence commencing with the discussion of modern oil fuel systems and methods of conditioning fuel oils for use in present day engines followed by a review of present day propulsion, thrust and auxiliary systems. The subject of ship resistance and ship operation has been addressed as well as the application of modern systems to various ship types commonly found in the Canadian fleet. Areas for future research and development have been suggested and included in this section of the report, alternative fuels suitable for shipboard use have been identified together with some of the equipment necessary to utilize those fuels.

2.0 FUEL QUALITY AND EQUIPMENT

Over the past several years fuel quality and ship operating procedures have changed drastically. The most important changes observed in fuels available today are:

- higher densities, exeeding 1.0
- more widespread contamination with catalytic fines
- easier precipitation of asphaltanes
- increased ability to emulsity with water

All these properties of fuel oil can have very significant adverse effects on engine wear if not adequately treated. That is why a lot of research work has been carried out to develop modern fuel treatment practices. Since traditionally, heavy fuel oil for use in diesel engines has been treated by centrifugal separators on board ship, the research has gone towards exploration of alternatives to centrifugal separation. Many manufacturers and shipowners experimented with homogenizers and filters, and some even dispensed with the separator altogether owing to the seemingly high capital and maintenance costs.

However, despite numerous benefits claimed in favour of these new methods, recent publications and technical papers have emphasized the importance of the centrifuge, reinforcing the view that all modern diesel vessels burning heavy fuel should be fitted with three separators. The other equipment or treatment should be considered only as supplementary means which help to improve the quality of fuel already cleaned by centrifuging.

Properly designed fuel treatment systems containing recently recommended arrangements, as well as adequate fuel treatment practice, may result in substantial fuel cost savings.

3.0 PROPULSION POWER SYSTEMS

At the present time propulsion power systems of merchant ships all over the world are almost entirely dominated by three types of machinery: direct drive slow speed diesel engines, geared medium speed diesel engines; and geared steam turbines.

Before the oil crisis much emphasis was placed on developing these types of machinery, with respect to ease of maintenance and to suit automatic control and unattended operation. The escalation of fuel prices left engine manufacturers facing a market demand for engines with high fuel efficiency. Over the last few years remarkable improvements in engine efficiency have taken place. Slow speed diesel engines with specific fuel consumption, as low as 180g/kwh, are now available, and even further reductions are claimed for the new designs being developed.

Medium speed diesel engines with advantages such as; reduced weight and space requirments; as well as the freedom to choose the optimum propeller r.p.m. through a reduction gear; and the recently developed capability of burning heavy and inexpensive fuels, have become a real alternative to the slow speed diesels despite the fact that their specific fuel consumption is about 10% higher.

Reductions in fuel consumption were achieved through fresh optimism on the combustion and scavenging processes, together with the use of high efficiency turbo chargers. The most important features of these new solutions are constant pressure turbo-charging and the uniflow scavenging system, which were already well known, but recent computer analytical methods proved their superiority over other systems.

Higher injection pressures up to 1,200 bar which gives fuel droplets of 20 micron diameter; new designs of exhaust valves and their control; as well as fuel valves and many other, sometimes small, details complete a picture of the modern diesel engine. Such engines are much better suited for low load operation and may be a substantial source of fuel savings on certain routes where slow steaming is required.

Similarly, steam turbines have undergone a substantial change in their design and fuel consumption. However, their efficiency is still lower than diesel engines especially at part loads.

4.0 THE THRUST SYSTEM

The efficiency of the ship as a system depends not only on the efficiency of the internal parts (engine and power transmission), but to an equal extent on the external parts; the thrust converting system and hull appendages. The conventional fixed pitch open propeller, with aft end lines designed for smooth water flow, are slowly being refined to obtain greater efficiency and modified in some significant ways to overcome recently discovered hydro dynamic effects.

Propeller efficiency is influenced by a) propeller diameter, with larger diameter resulting in higher efficiency, b) propeller revolutions, with lower revolutions resulting in higher efficiency, c) the number of blades, with the fewer number resulting in higher efficiency, d) blade area, with the smaller blade areas resulting in higher efficiency, and e) blade surface roughness, with a smoother surface resulting in signficant efficiency gains. Off these opportunities, propeller r.p.m. (and hence diameter), the number of blades, and propeller roughness, offer the best opportunities for efficiency gains.

In addition to conventional propellers, Tip Vortex Free propellers, Contra-rotating propellers and Reaction Fin propellers, all designed to achieve hydrodynamic benefits, have been adopted by ship owners and can result in significant fuel savings. The real long term benefits of these systems are not yet known nor is their applicability to a wide range of vessels fully understood.

Ducted propellers have been used now for many years, particularly on vessels requiring high bollard pulls, or at least those vessels with generally low operating speeds. The efficiency benefits of these ducted propellers at such low speeds are well recognized as are the draw backs when the operating speed is in the more conventional 14 - 16 knot range. Hull appendages such as the Mitsui Integrated Duct Propeller (MIDP), semi-tunnel sterns and rudder bulbs all offer interesting reductions in fuel consumption. These appendages have been fitted to a variety of vessels, and while the initial results indicate substantial benefits, further experience may be necessary to encourage owners to adopt these systems.

5.0 AUXILIARY SYSTEMS

All auxiliary systems of a vessel, if carefully designed and operated, offer remarkable savings in fuel consumption. Usually the greatest potential for savings is in auxiliary systems producing electrical power.

Conventional arrangements of diesel engine or steam turbine driven generators are more efficient today due to improvements in prime movers. The largest savings may be achieved by use of the main engine, which is usually the most efficient prime mover onboard ship, to supply all electric power requirements. This involves the use of either; waste heat to power the electrical generating systems, or main engine driven electrical generators.

Power take-off from the main engine is very popular in propulsion plants with medium speed diesel engines geared to a CP propeller since alternators are constant speed machines and ships with CP propellers could easily operate at constant RPM regardless of load. This is not possible in slow speed diesel engines with fixed pitch propellers unless the alternator is provided with frequency converters, usually at high cost. Moreover, the physical size and therefore cost of a generator fitted to a slow speed engine is excessive unless gearing is incorporated.

The other source of savings comes from minimizing heat losses from the machinery by the use of waste heat recovery systems. Heat is usually recovered from the exhaust gases, and the charge air and cooling water. Exhaust gases are utilized more often, for generating electric power especially on larger vessels, by means of steam turbo generators. The other heat sources serves mainly in various heating arrangements. Through introducing newly developed components of waste recovery systems, such as dual pressure steam boilers, the overall efficiency of heat recovery has increased significantly and new shipowners can expect larger savings relative to the investment made in the necessary equipment. For a relatively small investment, quite large savings can be achieved, but as the percentage of heat to be saved increases, the investment in equipment also increases considerably.

Waste heat recovery is very attractive to shipowners since, once the initial investment has been made, other than maintenance costs, the benefits are at no cost.

6.0 SHIP RESISTANCE

The reduction of overall resistance of a ship can be achieved by making reductions in either or both of; a) frictional resistance due to the relative motion of the hull through the surrounding water and, b) residual resistance related to the wave generating affect as the ship moves through the water and/or wake components related to water flow around the vessel's stern. Both of these aspects have been shown to greatly affect a vessel's fuel consumption. Efforts to reduce frictional resistance and to amend the wave making and wake components of resistance have been very successful.

Skin friction, which is believed to account for up to 80% of the total ship resistance, is being reduced by a variety of coatings presently available. These are a) soluble matrix anti-fouling, typified by tropical and super tropical grades, b) contact leaching types generally classified as "high performance" anti-foulings and, c) self-polishing co-polymer anti-fouling.

Modification of the wave making and wake components has been achieved by the installation of bow and stern bulbs. The objective of these bulbs is to suppress the generation of bow and stern waves, which, being formed by ship motion energy, result in wasted fuel. Bulblous bows have been in use for many years and, more recently, Professor Inui in Japan has promoted the use of stern bulbs.

7.0 SHIP OPERATION

There are many options open to vessel owners to improve fuel consumption by effective decision-making systems supported by detailed measurement and monitoring of ship performance and its environment.

The easiest means is slow steaming, especially for operators not sailing to a liner schedule. The magnitude of slow steaming benefits depend also upon propulsion machinery, that is, whether the design is adapted to perform efficiently at lower loads. The efficiency of prime movers and propellers when operating at off-design conditions is usually poor. By introducing modifications, maximum efficiency can be matched with optimum speed. For example, it could be; replacement of the propeller with one better suited for the new speed; application of variable injection timing; or special injection nozzles in diesel engines, etc.

Another area for influencing fuel consumption is improved ship handling; to reduce additional resistance resulting from excessive rudder action; and accurate navigaton, to minimize extra distance travelled. To achieve this, the application of modern navigation aids is essential. Maintaining optimum draft and trim through careful monitoring and accurate calculations can also have a positive effect on fuel consumption.

Finally, weather routing has become a remarkable element in fuel economy, mainly due to the development of computers and satelites. Specialists in weather routing utilizing all available meteorlogical data, computers, and specific information about a vessel, can provide timely recommendations to a master and enhance safety and fuel performance.

8.0 APPLICATION OF FUEL EFFICIENCY MEASURES TO VARIOUS CANADIAN SHIPS

Of the many energy saving methods open to shipowners some are applicable to all ships while others are only useful for certain vessels. It is most important to detail the operating profile of the vessel before any special device is selected. It is necessary to carry out this exercise before the main propulsion engine and propeller are selected. The usefulness of the various types of energy saving equipment also depends upon whether an existing vessel is to be modified or a newbuilding is contemplated. Table 1 lists all fuel efficiency equipment which has been discussed in this report with an indication of the range of fuel savings the equipment may achieve and the suitability of the equipment for different classes of Canadian vessels.

It is not possible to add together all the fuel savings attainable by the various methods described in this study. Some savings reduce the possibilities of further savings while others are necessary to help the attainment of additional improvements. A really fuel efficient ship should be provided with as many combined efficiency measures as possible assuming that thorough economic analysis had been carried beforehand.

TABLE 1

LIST OF FUEL EFFICIENCY MEASURES APPLICABLE TO CANADIAN SHIPS

NO.	FUEL EFFICIENCY MEASURE	POSSIBLE SAVING IN FUEL COSTS %	POSSIBLE APPLICATION TO CANADIAN SHIPS*			
			LAKER	FERRY	OCEAN GOING	COASTER
	Fuel Quality and Equipment					
1.	Conversion from diesel oil to heavier fuels	<27	N,R	N,R	N,R	N,R
2.	Homogenisation	1	R	R	R	R
3.	Blending	<9	R	R	R	R
4.	Emulsification	<7	N,R	N,R	N,R	N,R
5.	Chemical treatment	<1	N,R	N,R	N,R	N,R
6.	Sludge from centrifuges burned in boilers	0.7	N,R	N,R	N,R	N,R
	Main Diesel Engines					
7.	Use of slow speed, long stroke diesel engine	<16	N	(N)	N	N
8.	Use of medium speed diesel engine	<16	N	N	N	N
9.	Modification of the existing engines to slow steaming	<3.5	R	R	R	R
	Main Steam Turbines					
10.	Re-engining to diesel	0-33	(R)	-	R	-
11.	Retrofitting steam to steam	<5	R	-	R	-
12.	Improvement in steam cycle					
	a) installation of economizer	1-3	R	-	R	-
	b) smaller main feed pump for reduced power operation	0.7-1.8	R	-	R	-
	c) increased number of active feedwater heaters	1.0-3.0	R	-	R	-
	d) cascade turbine bleed system	1.0-3.0	R	-	R	-
13.	Retrofitting of burners to more efficient in existing boilers (main and auxiliary)	<3	R	R	R	R
	Propellers and Stern Form					
14.	Large, slow revving propeller	<12	N,(R)	N,(R)	N,(R)	N,(R)
15.	Controllable pitch propeller	-3-10	N	N	N	N
16.	Reduced propeller roughness	<5.5	N,R	N,R	N,R	N,R
17.	Tip Vortex Free propeller	<24	N,R	N,R	N,R	N,R
18.	Contrarotating propeller	<15	-	(N)	(N)	-
19.	Reaction fins	<8	N,R	N,R	N,R	-
20.	Flow modifying nozzle	8-10	N,R	N,R	N,R	N,R
21.	Ducted propeller	<8	N,R	N,R	N,R	N,R
22.	Semi-ducted stern	<2	N,R	N,R	N,R	N,R
23.	Rudder bulb	<5	N,R	N,R	N,R	N,R

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TABLE 1 (CONT.)

LIST OF FUEL EFFICIENCY MEASURES APPLICABLE TO CANADIAN SHIPS

NO.	FUEL EFFICIENCY MEASURE	POSSIBLE SAVING IN FUEL COSTS %	POSSIBLE APPLICATION TO CANADIAN SHIPS*			
			LAKER	FERRY	OCEAN GOING	COASTER
	Auxiliary Systems					
24.	Main engine driven generators	2	N	N	N	N
25.	Exhaust gas heat recovery	7.0	N	N	N	N
26.	Jacket cooling water heat recovery	1	N	N	N	N
27.	Charge air heat recovery	1.5	N	N	N	N
28.	Main engine driven pumps and compressors	1	N	N	N	N
29.	Variable speed pumps	1	N,R	N,R	N,R	N,R
30.	Use of thermal fluids for heating pruposes	<1	N	N	N	N
31.	Natural ventilation for the engine room	<1	N	N	N	N
32.	Reducing of bunker tank numbers	0-2	N	N	N	N
33.	Lagging of bunker tanks	0-2	N	N	N	N
	Hull Form					
34.	Model testing in order to improve hull performance	1-8	N	N	N	N
35.	Use of self-polishing anti-fouling coatings	2-7	N,R	N,R	N,R	N,R
36.	Use of high tensile steel reducing weight of ship	<2	N	N	N	N
37.	Use of light alloys	<15	(N)	N	-	-
	Ship Operation					
38.	Speed reduction up to 20%	<30	R	R	R	R
39.	Use of high quality autopilot	0-2	N,R	N,R	N,R	N,R
40.	Weather routing	-3-3	N,R	N,R	N,R	N,R
41.	Draft and trim monitoring	2-4	N,R	N,R	N,R	N,R
42.	Main engine monitoring (also boilers)	2-10	N,R	N,R	N,R	N,R
43.	Fuel monitoring	0-2	N,R	N,R	N,R	N,R

Key to Symbols
* - In newbuilding - N
- For retrofittings - R

( ) - Less likely application
- More likely application

Some observations should be emphasized.

a) The fleet of Canadian lakers offers significant potential for improvement.

b) Steam propulsion, if not changed to diesel should be at least thoroughly investigated in terms of modifying steam plants.

c) Vessels powered by diesel engines should be investigated in order to make conversions enabling burning of heavier grades of fuels. In cases where such conversions are not possible at least fuel blenders may be fitted and used to lower fuel bills.

d) There is an overall trend for lake ships to be propelled by slow speed, heavy fuel burning diesel engines rather than by traditional steam turbines. While the slow speed diesel engine provides the lowest specific fuel consumption for propulsion purposes of open water ships it is probable that the medium speed engine in the father-son configuration, will provide the most economical propulsion machinery system for lakers.

e) The principles of using propellers with large diameter, low r.p.m., lower blade number, smaller blade area ratio, smooth blade surface are well established and are being increasingly followed on a world wide basis.

f) In cases where these principles have been applied, such as the Port Weller built CANADIAN ENTERPRISE, the use of a larger propeller used in conjuction with a flow modifying semi-tunnel stern demonstrated fuel saving of 10% over a sister ship with a smaller and higher revving propeller without the semi-tunnel stern.

g) The ducted propeller is a feature finding increasing application in Canadian lakers. Besides having the general benefits as applied on all cargo ships, the ducts used on lakers have an additional benefit. In some applications, steering nozzles have been used thereby eliminating the rudder. This not only improves the manoeuvrability of the ship, it also reduces the length of the ship aft of the engine room, thereby increasing the length of usable cargo space. This is a significant benefit in the case of lakers when maximum lengths are limited by the seaway lock dimensions. For ships with less stringent length limit, the higher capital and maintenance cost of a steering nozzle may make the use of a steering nozzle less attractive.

h) For ship resistance reduction, bulbous bows are increasingly being used and the recently built Great Lakes ocean going bulk carriers are fitted with this bow form. In addition to reducing the hydrodynamic resistance of the hull, improved ice breaking capability is claimed. Obviously, higher ice breaking capability will enable the ship to operate for a longer season, achieve a higher annual return on capital employed and hence be more "efficient".

i) Another method of reducing ship resistance is the use of self-polishing coatings. Due to the presence of ice the application of self-polishing coatings on Canadian ships will differ slightly from ships engaged in open sea trades. As self-polishing coatings have low abrasive resistance, these coatings will perform poorly and give very little protection to the hull steel in the ice belt. To overcome this, a combination of ice resistance coatings (such as Inerta 160 or Zebron) in the ice contacting area and the usual self-polishing copolymer in non ice contacting area will form a good combination.

9.0 FUTURE FUELS AND POWER SOURCES

A list of energy sources and alternative fuels which have potential for marine application has been published by the U.S. Maritime Transportation Research Board of the National Academy of Science. Table 2 presents this list of twenty energy sources along with a qualitative ranking for each source. The table needs some explanation:

- Direct use applies to using that particular energy source as the means to propel the vessel, indirect means that the energy source could be used to provide hydrogen or the various hydrogen carrier fuels.

- Level of technological development
  - High - Commercial State
  - Medium - Demonstration (Pilot) State
  - Low - Research State

- Present availability for use as a fuel
  - High - Widely Available
  - Medium - Available in Limited Quantities
  - Low - Not commercially Available

- Safety in shipboard handling
  - Equal - At least equal to the safety of residual fuel oil
  - Low - Less safe than residual fuel oil

- Probability of economic production
  - High - High probability of being produced at competitive costs
  - Medium - Marginal probability of being produced at competitive costs
  - Low - Not likely to be produced at competitive costs

- Potential market size for marine propulsion systems
  - High - Large number of vessels might adopt fuel
  - Medium - Moderate number of vessels might adopt fuel
  - Low - Few if any vessels would adopt fuel

TABLE 2

QUALITATIVE RANKING OF CANDIDATE ALTERNATE FUELS AND ENERGY SOURCES

	LEVEL OF TECHNOLOGICAL DEVELOPMENT	PRESENT AVAILABILITY FOR USE AS A FUEL	LOWER HEATING VALUE kJ/kg	SAFETY IN SHIPBOARD HANDLING	SAFETY TO PERSONNEL	PROBABILITY OF ECONOMIC PRODUCTION	POTENTIAL MARKET SIZE FOR MARINE PROPULSION SYSTEMS	TYPES OF PROPULSION SYSTEMS READILY ADAPTABLE TO FUEL BY YEAR 2000+	ADAPTABILITY TO EXISTING FUEL STORAGE SYSTEM	EXISTING SHIPS BY YEAR 2000	FUTURE SHIPS BY YEAR 2000	TIME FRAME
1. Synthetic Liquid Fuel Oil from Coal	Medium	Low	40,500	Equal	Less	High	High	1, 2, 3, 4	High	High	High	90's
2. Synthetic Liquid Fuels from Shale Rock	Medium	Low	42,500	Equal	Less	High	High	1, 2, 3, 4	High	High	High	80's
3. Synthetic Liquid Fuels from Tar Sands	High	Medium	(42,500)	Equal	Equal	High	High	1, 2, 3, 4	High	High	High	80's
4. Methyl Alcohol	High	Low	20,100	Less	Less	High	Medium	1, 3, 4, 5	Medium	Low	Low	90's
5. Methanol/Coal Slurries (40/60)	Medium	Low	23,300 26,000	Less	Less	High	Medium	4	Low	Low	Low	2000+
6. Ethyl Alcohol (Ethanol)	High	Medium	26,900	Less	Less*	Low	Medium	1, 3, 4, 5	Low	Low	Low	Present
7. Gasoline/Alcohol Blends (90/10)	High	Medium	(41,400)	Less	Less	Medium	Low	1, 3, 4, 5,	Low	Low	Low	Present
8. Pulverized Coal/Oil Slurries (40/60)	Medium	Low	36,700 39,500	Equal	Equal	High	High	2, 4	High	Medium	High	80's
9. Hydrogen	High	Low	120,000	Less	Less	Medium	Low	-	-	-	-	2000+
10. Ammonia	High	Medium	18,700	Less	Less	Medium	Low	-	-	-	-	2000+
11. Hydrazine	High	Low	17,000	Less	Less	Low	Low	-	-	-	-	2000+
12. Methane	High	High	50,000	Less	Less	High	Low	1, 3, 4, 5	Low	Low	Low	80's
13. Nuclear (D)(1) (I)(2)	High Medium	High Low	N.A. N.A.	N.A. Varies	N.A. Varies	High Varies	Low Low	1, 4 Varies	N.A. Varies	Low Varies	Medium Varies	Present 2000+
14. Coal	High	High	27,900 34,900	Equal	Equal	High	High	4	Low	Low	High	Present
15. Wood (Air Dried)	Medium	Medium	12,800 18,600	Equal	Equal	High	Low	4	Low	Low	Low	80's
16. Solar Energy (D) (I)	Low Low	Low Low	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Low	N.A. -	N.A. -	- -	- -	N.A. 2000+
17. Wave Energy (D) (I)	Low Low	Low Low	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Low	N.A. -	N.A. -	- -	- -	N.A. 2000+
18. Wind Energy (D) (I)	High Medium	High Low	N.A. Varies	N.A. Varies	N.A. Varies	Low Varies	Low Low	N.A. -	N.A. -	Low -	Medium -	Present 2000+
19. Ocean Thermal (D) (I)	Low Low	Low Low	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Low	N.A. -	N.A. -	- -	- -	N.A. 2000+
20. Ocean Current (D) (I)	Low Low	Low Low	N.A. Varies	N.A. Varies	N.A. Varies	N.A. Low	N.A. Low	N.A. -	N.A. -	- -	- -	N.A. 2000+

(1) D = Direct; (2) I = Indirect; 1-Gas Turbine; 2-Diesel and Free Piston; 3-Internal Combustion Piston Engine; 4-Steam; 5-Fuel Cell; N.A.-Not Applicable; ( )-Denotes Estimated Values; *-Denatured; **-Refer to NTRB Study; -Possibility of Adaption by Year 2000 too Remote to Consider.

- Adaptability to existing fuel storage sytems takes into consideration acceptability by Regulatory Agencies and Classification Societies.

  High - Adaptable with minor or no modifications
  Medium - Adaptable only after major modifications
  Low - Adaptation of fuel might require such extensive modifications of vessel or fuel handling systems as to make the change economically unattractive

- Overall ranking. Takes into consideration all the categories used in comparing the fuels for both existing and new construction.

- Time frame. Estimate of decade in which each fuel will become available in commercial quantities.

To evaluate the costs of the alternative fuels, Figure 1 has been prepared. The quoted costs are those for manufacturing fuels, to which should be added costs of storage, transportation and distribution. These additional costs, due to their high uncertainty, have not been assessed.

In the case of hydrogen, methane and natural gas the total cost of energy from these sources should be increased by the liquefaction cost since they will be used mostly in liquid form.

Another suitable method to compare alternative fuels is by thermal efficiency, i.e., the ratio of the obtained shaft horsepower to the required amount of energy contained in a basic resource. This measure of efficiency includes all energy lost between the resource and the engine output, e.g., conversion to fuel losses, transportation losses, losses in the engine etc. The losses for some fuels are referred to in Figure 2 .

Finally, Figure 3 shows the relative costs of the electric power produced from the different sources of energy. The cost of the power depends not only on the plant cost but also on how much of the time the power can be produced. This has been taken into account in this figure. Though the figure shows electric power costs, it can also be an illustration of the possible cost of power plants producing energy for direct ship propulsion.

10.0 FUTURE PROPULSION SYSTEMS AND EQUIPMENT

The wide range of options offers prospects for development of future propulsions systems and ship machinery. Some of the options discussed have the immediate prospect of adoption by the marine industry, other proposed ideas only have a remote potential of being translated into practical design.

Some types of coal fired propulsion systems have already been introduced on vessels recently built. Their economic success depends mostly on the price relationship between coal and oil. At the present time coal is not competitive with oil for ships' bunkers, but when this relationship changes, the proven technology will be advantageous for those shipowners involved in these experimental coal fired ships.

FIGURE 1

COST COMPARISON FOR THE PRODUCTION OF ALTERNATIVE FUELS

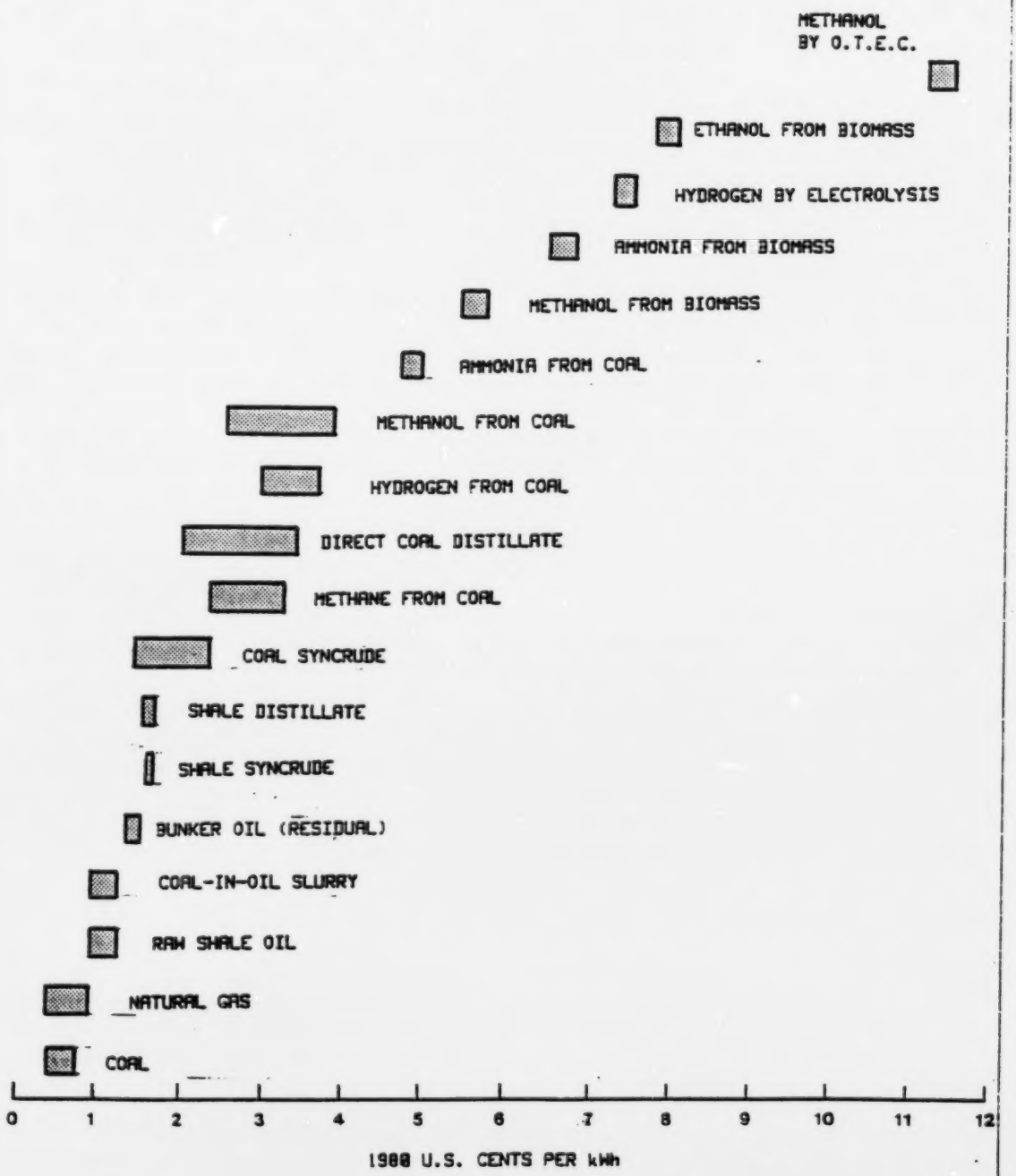

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FIGURE 2

OVERALL THERMAL EFFICIENCY
(MINE TO STEAM TURBINE SHAFT HORSEPOWER)

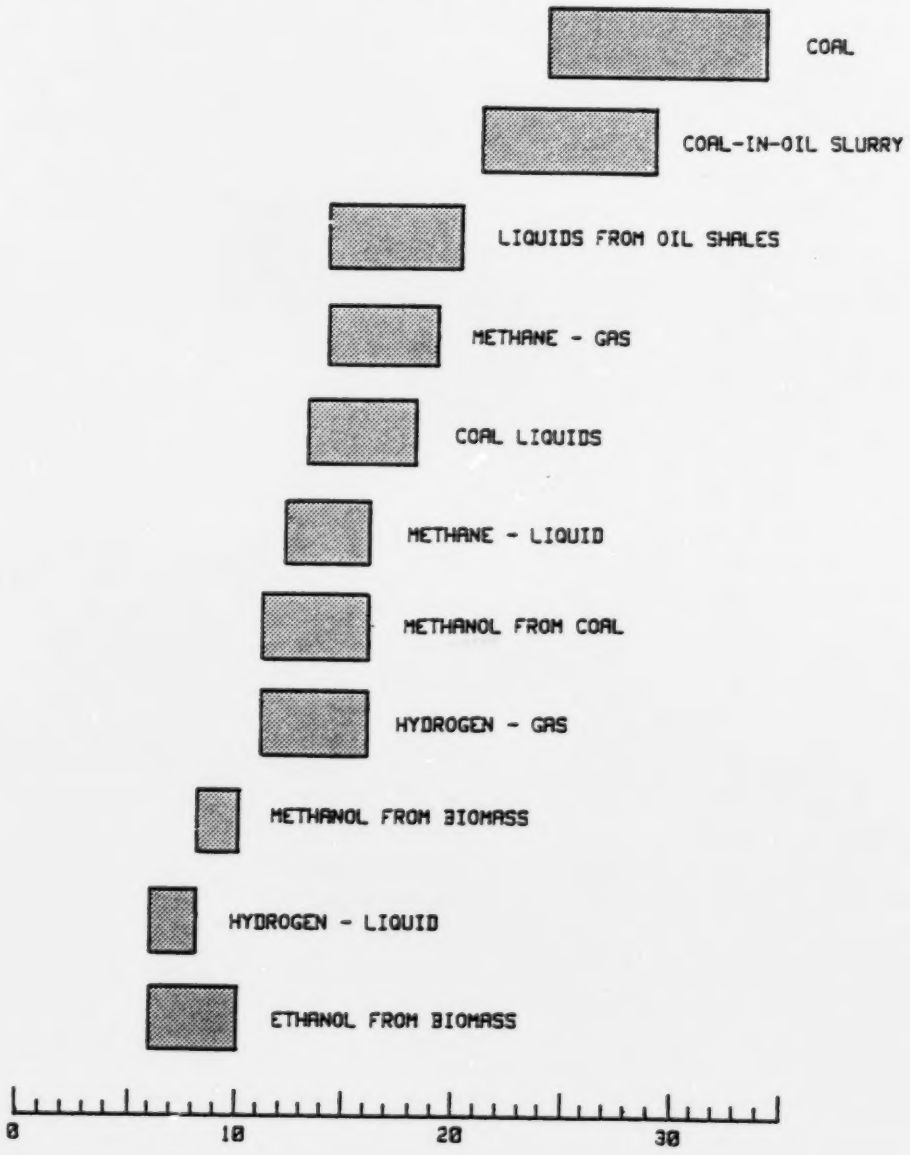

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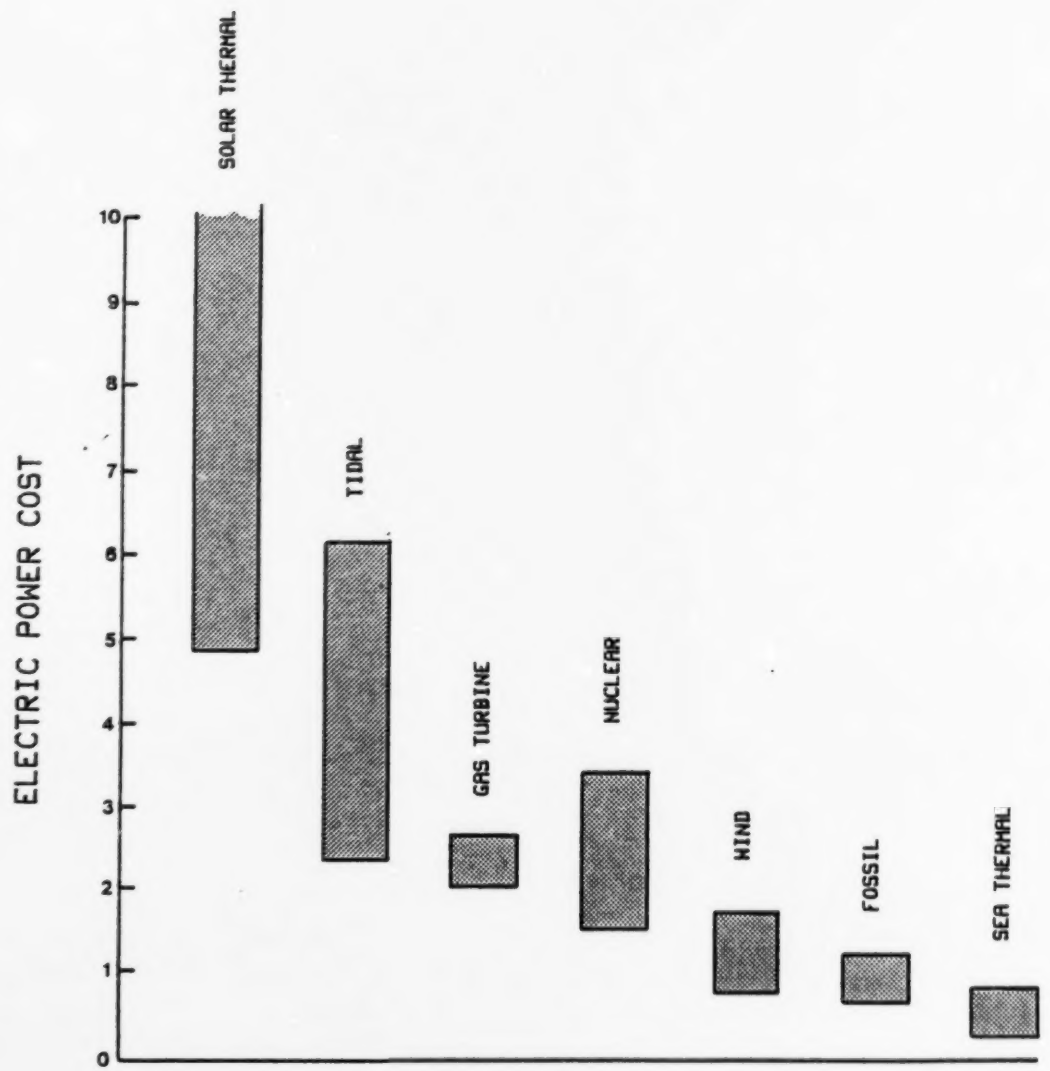
FIGURE 3

RELATIVE COSTS OF ELECTRIC POWER
FROM VARIOUS ENERGY SOURCES



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The only systems available at present, for the commrrcial conversion of coal to energy, are coal fired boilers providing steam for turbines. The alternative to this sytem is the use of coal as a fuel for closed cycle gas turbine systems, which will provide a far more economic use of the fuel and allow higher system efficiencies to be gained. Similarly, the Stirling engine using coal as a fuel also has potential but it would seem that the gas turbine is in a more advanced stage of development than high powered Stirling engines.

The development of fluidized bed boilers or combustors is believed to be an important component in the general development of more efficient heat engines capable of operating with low grade fuels. It is possible that the successful demonstration of a fluidized bed boiler, suitable for shipboard operation will be the stimulus required for accelerating the work on advanced ship propulsion systems such as the Stirling engine, closed cycle gas turbines and other topping cycles. The development of these advanced heat engines depends very much upon the availability of suitable materials for high temperature service.

The use of nuclear plants, except for special applications, is not expected to be justifiable for general ship propulsion use. The special applications where nuclear vessels could be justified are the high powered ships which might be required for use in the arctic. Vessels powered by nuclear boilers are already in use in the U.S.S.R. for this purpose. There is considerable opposition in the western democracies to the use of nuclear powered ships in any capacity, based upon environmental considerations, but there are no technical reasons why these vessels should not be built. The technology for nuclear vessels is available and has been used extensively for war ships. The capital costs and operating costs of a nuclear powered ship are uncertain, as the price of uranium fuel is governed more by political considerations than by free market forces. It is expected however, that nuclear fuels will in the future be in short supply and the use of exotic fast breeder reactors will perhaps be necessary. These reactors have not been used at sea and are in a state of early development ashore.

The use of fuel cells and other methods of direct conversion of chemical to electrical energy at sea is considered to be remote in the immediate future although cannot be discounted for the long term.